SECTION 17—SPACE SYSTEMS TECHNOLOGY

OVERVIEW

Space and space technology are vital for the military and economic security of the United States. Consequently, the United States has played a dominant world role in developing and using space technologies. If the United States is to maintain its military space leadership, the DoD must ensure that military space science and technology requirements are identified and documented so that appropriate space development programs receive the required resource support**.** Recent studies have shown that approximately 95% of space technologies can be categorized as dual use. The majority of the military technologies that fall in this category require greater radiation hardening than their commercial counterparts. The large number of numerous commercial communication satellites will in many cases drive the capabilities of many of the space technologies, which will then be used in all military space systems. This section covers critical space technologies: Electronics and Computers, Optronics, Power and Thermal Management, Propulsion and Sensors. Though there are many significant space technologies not listed, in Critical Developing Technologies, the following areas will be found: Astronics, Launch Vehicles, Qualification and Testing, Signature Control and Survivability, Space Structures and Space Systems Integration. Note: The term "Space Qualified" is no longer used and specific qualified/parameter levels are now used to describe when the item is militarily critical.

SECTION 17.1—ELECTRONICS AND COMPUTERS

OVERVIEW

This section covers critical discrete device and integrated circuit (IC) technologies (e.g., high-voltage analog circuits and digital signal processors) that are essential for our ability to deploy highly accurate ballistic missiles, and intelligence and surveillance satellites. Critical technologies in this area are focused on radiation hardening of the architecture and electronic components that fly in space.

Table 17.1-1. Electronics and Computers Militarily Critical Technology Parameters

Technology	Militarily Critical Parameters Minimum Level to Assure US Superiority	Critical Materials	Unique Test, Production, and Inspection Equipment	Unique Software and Parameters	Control Regimes
Architecture - Digital Signal Processors	Rad hard > 1 Mrad(Si) Throughput > 1 Million Operations Per Second (MOPs) Single Event Upset (SEU) (Linear Energy Transfer (LET) = 80 MeV cm^2/gm Reprogrammable SEU Resistant	None identified	None identified	Specific to each application	WA IL Cat 3
Architecture - High Speed Data Buses	Rad hard > 1 Mrad Throughput > 1 MOPs	None identified	None identified	Packet switching	WA IL Cat 3
Rad Hard Electronics Technology - Cryogenic Electronics	Rad hard > 500 krad	None identified	None identified	None identified	WA IL Cat 3
Rad Hard Electronics Technology - Field Programmable Devices	Rad hard > 500 krad Density > 5k gates	None identified	None identified	None identified	WA IL Cat 3
Rad Hard Electronics Technology - Nonvolatile Memory	Rad hard 1 Mrad Retention > 10 years Endurance > 101^2 cycles	None identified	None identified	None identified	Identify
Rad Hard Electronics Technology - Packaging	Rad hard > 10 Mrad Hermetic seal Density improvement > 10 X	Thin film SOI	Rad hard test facilities	Software for analysis of dose - rate upset and survivability SGEMP	None
Materials - Dielectrically Isolated (SOI)	Film thickness < 0.3 mm Uniformity > 95% Defects, $10/cm^2$	Not applicable	None identified	None identified	None
Software	Fault-tolerant Reprogram < 5 sec after detection On-orbit reprogrammable	None identified	None identified	None identified	None

SECTION 17.2—OPTRONICS

OVERVIEW

The critical space optics (optronics) technologies can be divided into four classes. The first is the design of the optical systems and components. The second area involves production methods for highly accurate, lightweight optical components. The third area is the specialized, sometimes exotic materials used for these optics. The fourth area is precision metrology associated with the fabrication and certification of space optics and the in situ characterization of the surface during operations. Optics are grouped as either cooled or uncooled. Cooled optics are most commonly used in military High Energy Laser (HEL) applications. Uncooled optics fall into two basic categories. First, mirrors for surveillance, reconnaissance, acquisition, pointing, tracking and communication applications. Most of these optics require high reflectivity coatings, partially transmissive or selective wavelength coatings, or coatings with holographic elements. Most of the optics in this category are dual use. The second category consists of the advanced transmissive component typified by single-crystal silicon optics, which allows for the substitution of very expensive, complex, heavy components with lightweight, inexpensive components. It is this category of optics that are used exclusively in military applications. What makes space optics (optronics) unique are the demanding environmental conditions in the launch-phase and when on-orbit. These conditions involve launch loads up to 20 g; vibration > 120 dB; contamination on orbit by outgassing of satellite systems; atomic oxygen attack; and degradation due to the impact of micrometeorods and space debris.

Table 17.2-1. Optronics Militarily Critical Technology Parameters

TECHNOLOGY	Militarily Critical Parameters Minimum Level to Assure US Superiority	Critical Materials	Unique Test, Production, and Inspection Equipment	Unique Software and Parameters	Control Regimes
DIRECTED ENERGY OPTICS	< 10^{-3} Absorption w/cm^2 > 10^4 w/cm^2 Incident Radiation	None identified	None identified	None identified	WA IL Cat 6 WA ML 19
LIGHTWEIGHT SPACE OPTICS	< 20% Bulk wt 30 kg/m^2 arial density total wt >10 kg > 1 m aperture	None identified	Tooling accuracy and foot print pressure Optical figure testing	None identified	WA IL Cat 6 WA ML 19
PASSIVELY & ACTIVELY COOLED OPTICS	> 10^4 w/cm^2 Incident Radiation for 30 sec	None identified	None identified	None identified	WA IL Cat 6 WA ML 19
ADAPTIVE OPTICS - COOLED AND UNCOOLED	> 10 cm Aperture 100 Hz bandwidth 1/2 1 flatness for > 100 Hz Bandwidth 1–0.5 mm	None identified	None identified	Controller	WA IL Cat 6 WA ML 19
SILICON OPTICS	Single crystal substrate w/optical coating, < 200 ppm absorption total > 25 cm aperture > 200 ppm optical scatter	None identified	None identified	None identified	WA IL Cat 6 WA ML 19
OPTICAL COATINGS	Scatter, 10^{-3} w/cm^2 and Absorption < 10^{-3} (For surface > 30 cm dia)	None identified	None identified	None identified	WA IL Cat 6 WA ML 19
SEGMENTED OPTICS	> 1 m aperture equivalent	None identified	None identified	Controller	WA IL Cat 6 WA ML 19

SECTION 17.3—POWER AND THERMAL MANAGEMENT

OVERVIEW

The key features of power sources for spacecraft are efficiency, lightweight, long-duration and reliability. For most of these systems both the technology and products will be available in the international marketplace. Withholding the production technology for as long as possible yet aggressively selling the products will offer the best chance for the United States to maintain a lead in space power. For thermal management numerous new technologies are being integrated not only to manage the heat transfer but to greatly reduce the weight.

Table 17.3-1. Power and Thermal Management Militarily Critical Technology Parameters

TECHNOLOGY	Militarily Critical Parameters Minimum Level to Assure US Superiority	Critical Materials	Unique Test, Production, and Inspection Equipment	Unique Software and Parameters	Control Regimes
SOLAR - PHOTOVOLTAIC	Specific Power > 300 W/m^2 Beginning of Life (BOL) at 28 °C at cell level	None identified	None identified	None identified	None

SECTION 17.4—PROPULSION FOR SPACE SYSTEMS

OVERVIEW

Emerging critical propulsion technologies are grouped in three basic categories: chemical (which includes liquid, cooled and hybrid systems), low-thrust electrical, and nuclear thermal. Electric propulsion can provide efficient station-keeping and maneuvering capabilities. Each of these technologies has considerable potential and R&D growth. Low-cost solids and low-pressure, high-tolerance liquid propellant systems or hybrids are the leading candidates to meet our projected first stage propulsion needs. Nuclear thermal propulsion appears to be very attractive for high-energy upper stage propulsion and for co-generated electrical output systems; however, it must overcome additional environmental challenges to reach its full space potential. The majority of the propulsion technologies are dual use. Areas of further development include high-energy density propulsion materials, improved propellant bonding, and advanced cryo-cooling and storage. These technologies all have weapons of mass destruction implications. For most applications an adversary does not need this level of sophistication to achieve a respectable propulsion capability.

Table 17.4-1. Propulsion for Space Systems Militarily Critical Technology Parameters

Technology	Militarily Critical Parameters Minimum Level to Assure US Superiority	Critical Materials	Unique Test, Production, and Inspection Equipment	Unique Software and Parameters	Control Regimes
Propulsion, Electric	Low power 1.5 to 10 kW High power > 10 kW >1500 hour life	High temp. > 3000 °C materials for anodes, cathodes and windows.	None identified	None identified	None
Storage and Refrigeration, Cryogenic Propellant	Loss rate < 30%/yr Temperature < 100 °K	Dimensionally stable thermal protection materials	Production - stir friction welding equipment for cryogenic storage tanks. High temp. ablators.	None identified	WA IL Cat 9 WA ML 9
Propulsion, Solid Rocket	I(t) > 1.1 MN F(vac) > 220 kN I[sp(vac)] > 2.4 kN/kg Stage mass fraction > 88% Propellant solids loading > 86%	None identified	Production: large scale mixing, casting, fabrication facilities and equipment. Test: specially designed development and testing (sea level and altitude) facilities.	Validated data: Service life, flaw effect, and other specialty analysis codes, mission analysis codes	WA IL Cat 9 WA ML 4 MTCR 15, 16
Composite Motor Cases	Diameter > 0.61m PV/W > 2.54×10^6	Resins, high-strength fibers, high-temp. resins (> 200 °F), long shelf life resins.	Production - 4 and 5 axis filament winding machine, 3, 4, and 5 degrees of freedom braiding mach., large winding and curing equipment.	Specially developed design and analysis codes, controller software used in manufacture. Software to control winding mach., resin manufacturing, and impregnation, resin transfer molding and similar technologies	WA ML 4

(Continued)

Table 17.4-1. Propulsion for Space Systems Militarily Critical Technology Parameters (Continued)

Technology	Militarily Critical Parameters Minimum Level to Assure US Superiority	Critical Materials	Unique Test, Production, and Inspection Equipment	Unique Software and Parameters	Control Regimes
Thrust Vector Control Systems	Total angular distance > ± 5 degrees Angular velocity > 20 deg/sec Angular acceleration > 40 deg/sec^2	Any high-temperature and erosion resistant metal, metal matrix or ceramic matrix composites for intrusive vane based TVC. High-temp. composite materials and insulators/shim materials (> 2000 °F).	Production - special machining or forming of high-temp, erosion-resistant materials, shim manufacture, controllers, special manufacturing processes associated with the type of TVC concept. Test - high-temperature strain gauges and thermocouples.	Control software and specially designed analysis codes	WA IL Cat 9 WA ML 4
Nozzles	Thrust > 45 kN Max. erosion rate < 0.075 mm/sec Production times < 3–6 months for carbon-carbon to densities > 1.7 g/cc	Carbon-carbon, hi-temp., low erosion materials (> 2500 °C). The material chosen can depend upon the exhaust environ-ment. Silicon-based nozzle materials may work well with hybrid rockets; they do not work well with SOTA solid rockets.	Production: Equipment for manufacturing of carbon-carbon material. Composite curing equipment. Equipment for depositing films of metal, diamond, etc. onto substrates. Large curing and winding machines, 3, 4, and 5 degrees of freedom braiding mach.	Design codes, Finite Element analysis and thermal analysis codes, control software used in design, test, and fabrication	WA IL Cat 9 WA ML 4
High-Energy Propellant Ingredients	I[sp(vac)] > 2.4 kN/kg	CL20, RDX, HMX, ADN, TNAZ, HADN, Fine Iron Oxide, advanced energetic oxidizers, fuels, and binders. Fuels and Oxidizers and additives for liquid propulsion systems	None identified	Chemical analysis, reaction analysis codes, chemical structure, est. of chemical and physical properties of energetic molecules, quality control, performance prediction.	WA ML 8, 18, 22 MCTR 4, 16
Launch Vehicle Propulsion-Reusable LO_2/LH_2	5 re-uses w/o refurbishment 0.9995 reliability I(sp) > 450 kN 250 k/lb thrust	See Subcomponents for liquid propulsion	Production - stir friction welding equipment for tank fabrication. Electro-deposition, electro-discharge or other special equip. for prod. of adv. thrust chambers or micro-orifice, liq.-prop. injectors.	Specially designed launch and cost-analysis codes	WA IL Cat 9 WA ML 4 MTCR 1, 2, 3, 15

(Continued)

Table 17.4-1. Propulsion for Space Systems Militarily Critical Technology Parameters (Continued)

TECHNOLOGY	Militarily Critical Parameters Minimum Level to Assure US Superiority	Critical Materials	Unique Test, Production, and Inspection Equipment	Unique Software and Parameters	Control Regimes
LAUNCH VEHICLE PROPULSION-EXPENDABLE - LO_2/LH_2 UPPER STAGES	> 550 k/lb sea level thrust 450 sec I[sp(vac)]	See Subcomponents for liquid propulsion	Production - stir friction welding equipment for tank fabrication. Electro-deposition, electro-discharge or other special equip. for prod. of adv. thrust chambers or micro-orifice, liq.-prop. injectors.	Specially designed launch and cost-analysis codes	WA IL Cat 9 WA ML 4 MTCR 1, 2, 3, 15
LAUNCH VEHICLE PROPULSION-EXPENDABLE - LO_2/LH_2 BOOSTER	> 300 k/lb sea level thrust 275 sec I[sp(vac)]	See Subcomponents for liquid propulsion	Production - stir friction welding equipment for tank fabrication. Electro-deposition, electro-discharge or other special equip. for prod. of adv. thrust chambers or micro-orifice, liq.-prop. injectors.	Specially designed launch and cost-analysis codes	WA IIL Cat 9 WA ML 4 MTCR 1, 2, 3, 15

SECTION 17.5—SENSORS FOR SPACE SYSTEMS

OVERVIEW

Current electro-optic sensors allow the United States to examine activity at any point on or near the earth. The electronic readout capability of the newer sensors gives the satellite an essential indefinite life on station as compared to earlier systems that used film and were limited by the magazine size. In cases where scattered sunlight or thermal radiation is not adequate to form images of sufficient detail and clarity, laser illumination can be used. These capabilities are central to the U.S. early warning capability for missile launchers and locating nuclear detonations and are also a major component of tactical and strategic data collection. Synthetic Aperture Radar (SAR) is well-suited for space applications since the distance from the target has less of an impact on imagery resolution than with most other radar systems. The most common ELINT satellites are designed to receive radio and radar emanations of ships at sea, mobile air defense radars, fixed strategic early warning radars, and other vital military components for the purpose of identification, location, and signals analysis. Some critical astronautic technologies are:

- Space, IR Sensors, which are the key element in sensor systems such as the Defense Support Program (DSP), that monitor missile launches.
- IR detector arrays, sometimes referred to as focal plane arrays (FPAs), including one-, two-, three-dimensional arrays enabling imaging analogous to the vidicons in the visible spectrum, which provide the ability to "see" at night, and an improved ability to penetrate cloud cover.

Though all of these technologies have dual-use capability the active sensors are more limited in their applications.

Table 17.5-1. Sensors for Space Systems Militarily Critical Technology Parameters

TECHNOLOGY	Militarily Critical Parameters Minimum Level to Assure US Superiority	Critical Materials	Unique Test, Production, and Inspection Equipment	Unique Software and Parameters	Control Regimes
SENSOR - INFRARED DETECTOR ARRAY	One or more elements 128 x 128 array level Rad-Hard > 500 krad (Si) Single event rate < 1 frame/30 frames	Impurity Banded Materials (SI:As)	Processing for Binary compounds (HgCdTe)	None identified	WA IL Cat 6